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Evaluation of the effects of habitat restoration on fish species at risk within Crown Marsh, Long Point Bay, Lake Erie, Ontario

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The purpose of this research is to determine if the restoration of Long Point Crown Marsh, Lake Erie was beneficial for fishes and supported local fish recovery efforts as there are five fish species at risk found in this region. Crown Marsh has been invaded by the invasive common reed (*Phragmites australis*). To restore the habitat and provide more open water, dredging occurred to create ponds connected to Long Point Bay. To evaluate the effect of this habitat restoration on fishes, Fisheries and Oceans Canada (DFO) and the Ontario Ministry of Natural Resources and Forestry (OMNRF) sampled six ponds from 2012 to 2014. Four created ponds and two reference ponds with minimal human disturbance were sampled using enclosure seining methods. In addition to sampling the fishes, habitat data were collected and water depth and temperature were recorded over time using level loggers. Eastern Sand Darter (*Ammocrypta pellucida*) and Spotted Gar (*Lepisosteus oculatus*), threatened species at risk, were not caught during these sampling events. The most recently created ponds, Ankney Pond and Kozac Pond, supported four species at risk including Grass Pickerel (*Esox americanus vermiculatus)*, Lake Chubsucker (*Erimyzon sucetta)*, Pugnose Shiner (*Notropis anogenus)*, and Warmouth (*Lepomis gulosus)* at various times throughout sampling. The created Thompson Pond and West Feed Pond supported Grass Pickerel, Lake Chubsucker, and Pugnose Shiner, but not Warmouth. The fish assemblages differed among ponds and over time. Habitat varied among ponds, as newly created Ankney Pond and Kozac Pond exhibited less submerged vegetation and more open water habitat compared to the reference ponds. They were also shallower than the reference ponds and West Feed Pond. None of the ponds were large enough to support the minimum viable population size for Lake Chubsucker. Also, many of the ponds occasionally experienced very low water levels, high water temperatures in the summer, and low dissolved oxygen. Further research should be completed on the composition of fish assemblages in the channels, the movement of individuals among ponds and Long Point Bay, and the over-wintering habitats in the created ponds. The ponds should be constructed as a gradient with the deepest portion of the pond near the channel to prevent stranding when water levels are low. Multiple connections out of the ponds should be made to promote migration in stressful habitat conditions. Also, pond maintenance should be avoided to support the establishment of aquatic macrophytes.

Évaluation des effets de la restauration de l'habitat sur les espèces de poissons en péril dans le marais Crown de la baie Long Point sur le lac Érié en Ontario

RÉSUMÉ

Cette recherche a pour objet de déterminer si la restauration du marais Crown à Long Point sur le lac Érié a été bénéfique aux poissons et a appuyé les efforts de rétablissement des poissons locaux, car cinq espèces de poissons en péril se trouvent dans cette région. Le marais Crown a été envahi par le roseau commun (*Phragmites australis*) envahissant. Pour restaurer l'habitat et fournir une plus grande étendue d'eau libre, on a effectué des travaux de dragage de manière à créer des étangs reliés à la baie Long Point. Pour évaluer l'effet de cette restauration de l'habitat sur les poissons, Pêches et Océans Canada (MPO) et le ministère des Richesses naturelles et des Forêts de l'Ontario ont prélevé des échantillons dans six étangs de 2012 à 2014. Les échantillons ont été recueillis dans quatre étangs créés et deux étangs de référence ayant un très faible niveau de perturbation d'origine anthropique selon les méthodes de pêche à la senne dans des boîtiers. En plus de l'échantillonnage des poissons, des données sur l'habitat ont été recueillies et la profondeur et la température de l'eau ont été enregistrées dans le temps à l'aide d'enregistreurs de niveau. Le dard de sable (*Ammocrypta pellucida*) et le lépisosté tacheté (*Lepisosteus oculatus*), des espèces en péril menacées, n'ont pas été capturés au cours de ces activités d'échantillonnage. Les étangs les plus récemment créés, l'étang Ankney et l'étang Kozac, abritaient quatre espèces en péril, à savoir le brochet vermiculé (*Esox americanus vermiculatus)*, le sucet de lac (*Erimyzon sucetta)*, le méné camus (*Notropis anogenus)* et le crapet sac-à-lait (*Lepomis gulosus)*, à différents moments de l'échantillonnage. Les étangs créés, soit l'étang Thompson et l'étang West Feed, sont habités par le brochet vermiculé, le sucet de lac et le méné camus, mais pas par le crapet sac-à-lait. Les assemblages de poissons variaient en fonction de l'étang et du temps. L'habitat variait en fonction de l'étang, car les étangs récemment créés, l'étang Ankney et l'étang Kozac, présentent moins de végétation submergée et plus d'habitats en eaux libres que les étangs de référence. Ils étaient également moins profonds que les étangs de référence et l'étang West Feed. Aucun des étangs n'était assez grand pour soutenir de la taille de la population minimale viable pour le sucet de lac. De plus, bon nombre des étangs ont parfois connu des niveaux d'eau très faibles, des températures élevées de l'eau pendant l'été et de faibles concentrations d'oxygène dissous. Il faut approfondir les recherches sur la composition de l'assemblage de poissons dans les chenaux, le déplacement des individus dans les étangs et la baie Long Point, ainsi que sur les habitats d'hivernage dans les étangs créés. Les étangs doivent être construits en pente, la partie la plus profonde de l'étang devant être proche du chenal pour prévenir l'échouement lorsque les niveaux d'eau sont bas. Il devrait y avoir plusieurs embouchures permettant de sortir des étangs afin de favoriser la migration dans des conditions de stress dans l'habitat. De plus, il faut éviter d'entretenir l'étang pour appuyer l'établissement de macrophytes aquatiques.

INTRODUCTION

Long Point Bay and its surrounding wetlands are designated as an UNESCO (United Nations Educational, Scientific and Cultural Organization) Biosphere Reserve due to the variety of habitats that support diverse flora and fauna (Thomasen et al. 2013). Long Point Crown Marsh, a coastal wetland, is located within this complex. Crown Marsh provides important habitat for migratory waterfowl as they use it for breeding and foraging (Meyer et al. 2010). It is also important for fishes as they use wetlands as nursery habitats, spawning grounds, and to feed (Jude and Pappas 1992). The diversity of habitats reduce the risk of predation and provide shelter from harsh lake conditions. An earlier study by Mahon and Balon (1977) found 33 fish species to be dependent on wetland habitats in Long Point ponds. Within Long Point Bay, Crown Marsh is one of the locations with the greatest number of fish species (Whillians 1985). Seine-based surveys of Crown Marsh in the mid-1980s detected 25 fish species, including young-of-the-year (YOY) of 16 species and three fish species at risk (Timmerman 1992). Crown Marsh wetlands are critical habitat for species at risk, Eastern Sand Darter (*Ammocrypta pellucida*), Lake Chubsucker (*Erimyzon sucetta*), and Pugnose Shiner (*Notropis anogenus*) (DFO 2010; DFO 2011; DFO 2012). It is also important habitat for Grass Pickerel (*Esox americanus vermiculatus*) and Warmouth (*Lepomis gulosus*).

Lake Erie coastal zones have been assessed to be highly vulnerable to invasion by common reed (*Phragmites australis)* (Carlson Mazur et al. 2014). At Long Point, wetland ecosystems are being transformed by the spread of common reed, an invasive perennial reed species. The species is able to reproduce quickly through seed dispersal and rhizome growth, create impenetrable stands, and outcompete native wetland plants. A reduction in plant diversity has subsequently occurred (Wilcox et al. 2003). In addition, the spread of common reed converts the wetland into more terrestrial environments, as it promotes the accumulation of sediment and organic matter (Wilcox et al. 2003; Schummer et al. 2012). From 1999 to 2006, common reed replaced 48 ha of wetland in the Crown Marsh, which represents an annual increase in coverage of 27.8%. By 2014, 157 ha of Crown Marsh had been converted to stands of common reed (OMNRF, unpublished data). Consequently, the spread of common reed has reduced native plant diversity and indirectly impacted taxa dependent upon native habitats (Schummer et al. 2012).

Across the Laurentian Great Lakes basin, changes to temperature and precipitation are predicted to substantially increase the amount of habitat suitable for common reed (Carlson Mazur et al. 2014). Currently, common reed comprise 1.32% of total wetland area in the Great Lakes, and 7.0% of total wetland area is suitable for common reed colonization (Carlson Mazur et al. 2014). The majority of wetland area suitable for colonization is found in Lake Huron, Lake Erie, and Lake Michigan (Bourgeau-Chavez et al. 2013). Climate change models for the Great Lakes indicate that by 2050, 25.7% of coastal wetland zones will be suitable for common reed (Carlson Mazur et al. 2014). The increase in common reed will result in many negative impacts to the ecosystem including loss of native wetland vegetation, reduction in habitat quality for wildlife, and a decrease in nitrogen and phosphorus availability (Findlay et al. 2002; Wilcox et al. 2003). In Lake Erie, climate change models predict a decrease in water level by 0.83 m (Mortsch et al. 2006). The predicted water level change would increase the amount of suitable habitat for common reed, as it tends to colonize areas <1 m in depth (although common reed has been found in waters up to 2 m deep) (Crisman et al. 2014). If common reed was found in Long Point Bay at 2 m in depth, it could spread throughout the inner Long Point Bay and substantially degrade critical habitat for fishes at risk, like the Pugnose Shiner (McCusker unpubl. rep.).

In response to wetland habitat loss since the common reed invasion, federal, provincial, and municipal governments and non-government waterfowl conservation groups have begun to mechanically remove common reed and create open water ponds to improve waterfowl habitat. Other methods used to remove common reed in Great Lakes wetlands have been burning, herbicide, and flooding, but none of these methods can be sustained indefinitely (USGS Great Lakes Science Center 2013). Compared to monotypic cattail (*Typha glauca* x *T. angustifolia*)-common reed stands, these created ponds have a greater diversity of plants and support a greater relative abundance of macroinvertebrates and marsh birds (Schummer et al. 2012). It is unknown how the five wetland fish species at risk found in the Long Point Bay region would respond to the creation of the ponds, and whether the ponds are a net benefit and support local fish population recovery, or function as ecological traps. If individuals selected for the created ponds and the habitats were low-quality and did not allow for reproduction and survival, the ponds would be considered an ecological trap. Wetland improvement projects are widespread throughout inner Long Point Bay. Given the financial cost to control established common reed stands, it is important that applied strategies have the desired ecological benefits. Research on the effectiveness of wetland restoration activities to recover Lake Chubsucker and Pugnose Shiner populations has been identified as a priority recovery action (Staton et al. 2010; DFO 2012).

Fisheries and Oceans Canada (DFO) and the Ontario Ministry of Natural Resources and Forestry (OMNRF) undertook a three-year monitoring program in Crown Marsh to characterize fish use (with an emphasis on species at risk) and habitat quality of created open-water wetland habitats. Four ponds constructed at different times (1970s, 2010, 2012), and two natural ponds, which are reference sites, were sampled from 2012 to 2014. Two additional ponds were sampled in 2015 by OMNRF.

Using the Crown Marsh fish and wetland habitat data, the following objectives posed by the DFO species at risk program were addressed:

1. Compare and characterize fish assemblages and habitat conditions in created wetland habitats and reference sites.
2. Assess the value of the created habitats (sources, sinks) and provide approaches that could be used to maximize this value to species at risk fishes.

METHODS

STUDY AREA

The study was conducted at six ponds in Crown Marsh, Long Point Bay, Lake Erie, Ontario (Figure 1). The ponds are connected through channels to Long Point Bay. Four of the ponds were created and two were natural open-water areas that are minimally disturbed by maintenance activities. Ponds ranged in size from 0.33 to 4.78 ha, and the depth of the ponds ranged from 0.15 to 1.5 m depending on the year and season sampled (Table 1). All ponds were surrounded by stands of cattails and common reed.

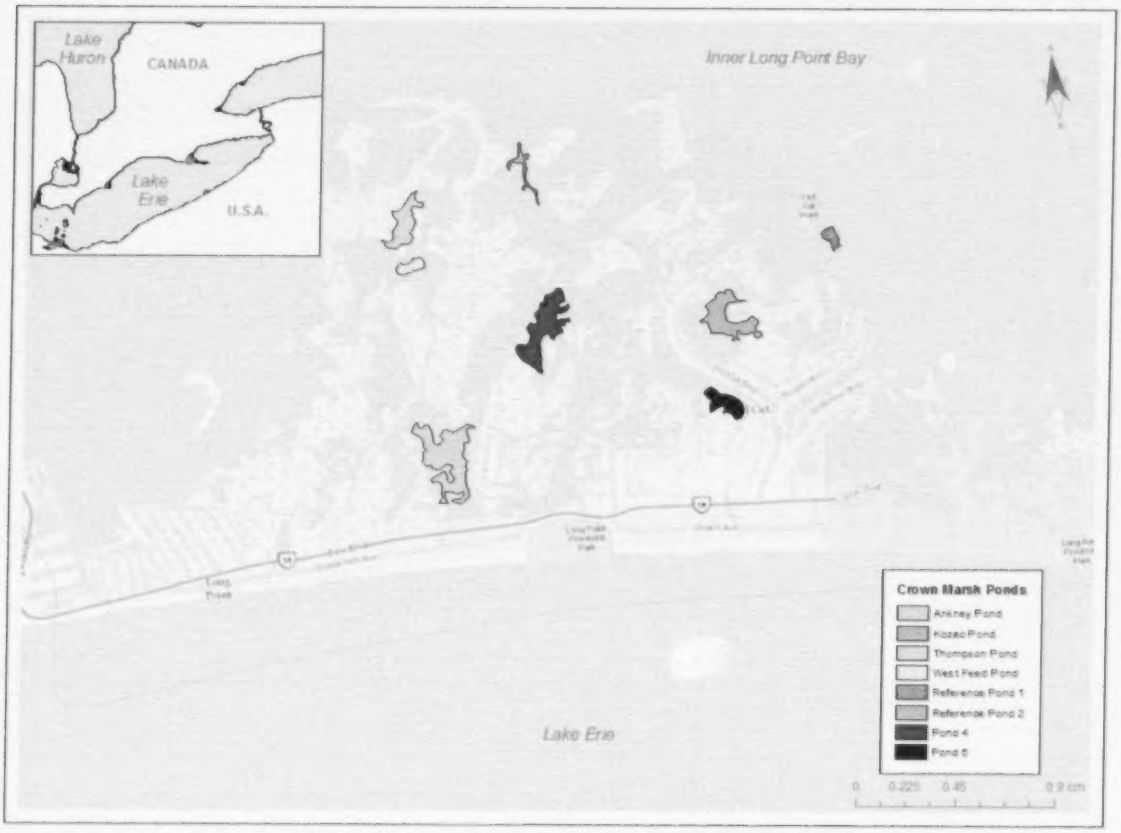

Figure 1. Locations of the dredged and natural ponds in Crown Marsh. Note that Pond 4 and 6 were drawn based on site coordinates and may not reflect exact pond shape.

Table 1. Characteristics of the Long Point Crown Marsh ponds sampled 2012–2015. Note that pond size may not reflect exact size and is an estimate.

	Pond size (ha)	Year created
Ankney Pond	4.78	2012
Kozac Pond	2.86	2012
Thompson Pond	2.06	2010
West Feed Pond	0.55	circa 1970s
Pond 4	3.5	Winter 2013/2014
Pond 6	1.37	Winter 2014/2015
Reference Pond 1	0.33	-
Reference Pond 2	0.55	-

FISH DATA COLLECTION

Fishes in each of the six ponds were sampled over three years (2012–2014) by DFO and OMNRF staff. In 2012, two summer sampling events were completed, whereas in 2013 and 2014, there was one spring and one summer sampling event. Each sampling event consisted of 4 days. Sampling took place July 16–19 and August 13–16 in 2012, May 27–30 and August 12–15 in 2013, and May 27–30 and August 5–8 in 2014.

At each pond, ten sampling sites were evenly distributed along the shoreline. An enclosure was made at each site using a 1.8 m deep and 22.9 m long seine net with a mesh size of 3 mm. Fishes in each enclosure were sampled using a 9 m x 1.8 m bag seine with a mesh size of 3 mm. Five successive seine hauls were taken at each site. Between each haul, a minimum of 5 minutes elapsed. After each haul, all fishes captured were counted and identified to species. Minimum and maximum lengths (mm) of each species were recorded. Digital or physical vouchers preserved in 10% formalin were taken for all species captured.

In 2015, OMNRF also sampled Crown Marsh fishes during the spring, summer, and fall with the same seining method. Two new ponds (Pond 4 and Pond 6) created during the winter of 2013/14 and isolated from Long Point Bay until fall 2015, were sampled. Fish sampling at Ankney Pond and Kozac Pond continued in the summer of 2015.

HABITAT DATA COLLECTION

During each sampling event, the following habitat characteristics were measured. Water quality including water temperature (°C), pH, dissolved oxygen (mg/L), conductivity (µS/cm), and turbidity (NTU) were measured using an YSI EXO1 water-quality sonde. At each sampling site, air temperature (°C), substrate, aquatic vegetation, riparian vegetation, and depth were assessed. The percent composition of different aquatic vegetation types in each enclosure (submerged, emergent, or floating) was visually assessed. Habitat without vegetation was recorded as open water. Riparian vegetation was characterized as the percentage of deciduous, coniferous, herbaceous, shrubs, and grasses at the sampling site. Substrate type was visually classified based on particle size using the Wentworth scale (Wentworth 1922) and it was recorded as the percentage of silt, clay, organic, rubble, cobble, sand, boulder, bedrock, hardpan, or concrete in each enclosure.

LEVEL LOGGER DATA COLLECTION

To examine trends in water temperature and water depth at the six ponds over time, level loggers were deployed in the spring of 2012–2014 (after ice-out). Deployment dates were May 30, 2012; April 13, 2013; May 11, 2013; and, May 8, 2014. In 2012, one logger was placed in each pond and was retrieved January 15, 2013. In 2013 and 2014, one additional logger was deployed in the channel connected to each pond and was retrieved October 29–30, 2013 and November 26, 2014, respectively. In 2013 and 2014, loggers were removed before winter to prevent loss and damage as observed after winter of 2013. In 2012, level loggers were lost in both reference ponds, therefore, data were only available for the created ponds.

In all three years, pressure and temperature data were recorded using 4 m Depth Titanium Water Level Data Loggers, U20-001-04-Ti made by Onset HOBO® Data Logger. To compensate for barometric pressure changes, an extra HOBO® U20 Water Level Logger was deployed at West Feed Pond to record the local atmospheric pressure by suspending the logger so that it would never be submerged in water. Only one reference was required as all logging locations were within a 15 km radius.

HOBO software was used to recover data from level loggers. The Barometric Compensation Assistant feature of HOBO software used the reference data to convert absolute pressure data from the water level loggers into depth of water in meters. Data were exported as semi-hourly readings into Excel and plotted to determine trends.

DATA ANALYSIS

Fish assemblage

For each of the ten sampling sites in each pond, 5-seine-haul catch data were pooled. Catch data were log+1 transformed prior to analysis to normalize the data. Reference pond data were pooled and differences between ponds over time were assumed to reflect natural variation. To test for differences in fish assemblages among ponds and over time, a non-parametric multivariate analysis of variance was completed. The test was run with the *adonis* function in the vegan package in R based on Euclidean distances and 999 permutations (Oksanen et al. 2010). *Adonis* was developed to test differences in species assemblages with different treatments. It can be based on any measure of dissimilarity and has no formal assumptions (Anderson 2001). There is no graphing function associated with *adonis*, so a principal component analysis (PCA) using a covariance matrix was used to visualize differences in fish assemblages among ponds. For the analysis, it was assumed that species detection probabilities did not vary across ponds or years.

Habitat

Differences in habitat among ponds and over time were tested using an analysis of covariance (ANCOVA). When ANCOVA results were statistically significant, the Tukey all-pair comparisons test was used to identify differences between ponds. Habitat variables included in the ANCOVA were submerged vegetation, emergent vegetation, floating vegetation, open water, water temperature, conductivity, dissolved oxygen, and turbidity.

Differences in habitat quality among ponds were also assessed by calculating the Wetland Fish Index (WFI) (Seilheimer and Chow-Fraser 2006). WFI uses species abundance or presence to determine the condition of Great Lakes coastal wetland habitats. WFI scores have been found to be correlated to water quality and macrophyte-based indices of wetland condition (Seilheimer et al. 2009). Index scores were calculated using the following equation where Y_i represents the abundance (log(x+1)), T_i represents niche breadth, and U_i represents tolerance of degradation. Niche breadth and tolerance towards degradation for each species was provided by Cvetkovic and Chow-Fraser (2011).

$$WFI = \frac{\sum_{i=1}^{n} Y_i T_i U_i}{\sum_{i=1}^{n} Y_i T_i}$$

WFI scores below 3.25 indicate a degraded wetland condition (Cvetkovic and Chow-Fraser 2011).

RESULTS

FISH ASSEMBLAGES

Over the four years, 60 sites were sampled at Thompson Pond, West Feed Pond, Reference Pond 1, and Reference Pond 2, and 70 sites were sampled at Ankney Pond and Kozac Pond. This resulted in fish collection data associated with 1,900 seine hauls. A total of 28,724 fishes were caught, representing 34 species (Table 2 and Table A.1). The most commonly occurring species were Blackchin Shiner (*Notropis heterodon*), Pumpkinseed (*Lepomis gibbosus*), Largemouth Bass (*Micropterus salmoides*), and Bluegill (*Lepomis macrochirus*). These four species made up 47.6% of the total number of fishes caught. Fish species at risk made up 8% of the total catch. Pugnose Shiner was the most abundant species at risk as it represented 6.9% of the total number of fishes captured. Seventy-percent of Pugnose Shiner were seined

from Reference Pond 1. Four fish species at risk (Grass Pickerel, Lake Chubsucker, Pugnose Shiner and Warmouth) were seined from the newly created Ankney Pond and Kozac Pond. Only three fish species at risk were captured from Thompson Pond and West Feed Pond (no Warmouth were captured) (Table 3). The threatened Eastern Sand Darter and Spotted Gar were not caught during sampling.

During the summer, YOY fishes were caught from all ponds (Table 4). Newly created Ankney Pond contained 17 species with YOY and 23 species with juveniles. YOY and juveniles representing all four species at risk were present in Ankney Pond. The number of species represented was comparable to reference ponds, and slightly higher than Thompson Pond and West Feed Pond. For YOY and juveniles, fewer species were collected from Kozac Pond; although, Grass Pickerel, Lake Chubsucker and Warmouth were all present.

Table 2. Summary of all fishes captured at each pond during each season, including number of fishes, number of species caught during the sampling period, total number of species caught in each pond, and number of unique species. A unique species was not found in other ponds. Ankney Pond and Kozac Pond were also sampled in 2015. 2012 A represents July sampling and 2012 B represents August sampling.

Pond	Sampling event	No. of fishes	No. of species	Total no. of species	No. of unique species
Ankney Pond	Summer 2012 A	1051	12	28	0
	Summer 2012 B	1008	17		
	Spring 2013	529	14		
	Summer 2013	781	20		
	Spring 2014	978	17		
	Summer 2014	1297	20		
	Summer 2015	2156	16		
Kozac Pond	Summer 2012 A	225	9	30	3
	Summer 2012 B	253	10		
	Spring 2013	153	12		
	Summer 2013	486	17		
	Spring 2014	1026	16		
	Summer 2014	356	12		
	Summer 2015	171	15		
Thompson Pond	Summer 2012 A	300	11	25	2
	Summer 2012 B	319	14		
	Spring 2013	614	14		
	Summer 2013	890	15		
	Spring 2014	523	15		
	Summer 2014	589	19		
West Feed Pond	Summer 2012 A	671	16	30	2
	Summer 2012 B	903	19		
	Spring 2013	1259	22		
	Summer 2013	1562	17		
	Spring 2014	1728	19		
	Summer 2014	732	21		

Pond	Sampling event	No. of fishes	No. of species	Total no. of species	No. of unique species
Reference Pond 1	Summer 2012 A	655	17	28	0
	Summer 2012 B	1695	23		
	Spring 2013	1162	19		
	Summer 2013	331	13		
	Spring 2014	1948	21		
	Summer 2014	489	20		
Reference Pond 2	Summer 2012 A	459	13	28	0
	Summer 2012 B	377	16		
	Spring 2013	327	17		
	Summer 2013	128	10		
	Spring 2014	325	11		
	Summer 2014	268	19		

Table 3. The number of four fish species at risk found collected from Crown Marsh ponds pooled across all sampling events 2012–2014. More-detailed summaries for each season and year are provided in Tables A2, A3, and A4 of the appendix.

	Kozac Pond	Ankney Pond	West Feed Pond	Thompson Pond	Reference Pond 1	Reference Pond 2
Lake Chubsucker	2	16	39	17	62	57
Grass Pickerel	5	23	23	2	9	24
Warmouth	3	13	0	0	6	2
Pugnose Shiner	1	27	252	211	1264	53

Table 4. Comparison of the number of young-of-the-year and juveniles of fish species seined from each pond (pooled over summers 2012–2014).

	Young-of-the-year		Juvenile	
	Total	Species at risk	Total	Species at risk
Ankney Pond	17	3	23	4
Kozac Pond	14	1	14	2
Thompson Pond	16	2	15	2
West Feed Pond	16	2	18	3
Reference One Pond	17	2	20	4
Reference Two Pond	18	3	12	3

Based on the size of individuals captured and known diet (Scott and Crossman 1973), six of the species captured are considered to be piscivores: Grass Pickerel, Largemouth Bass, Longnose Gar (*Lepisosteus osseus*), Northern Pike (*Esox lucius*), Rock Bass (*Ambloplites rupestris*), and Yellow Perch (*Perca flavescens*). Piscivores were most frequently captured in reference ponds. At these ponds, five of the six species were present at each sampling event. Fewer piscivore species were present at constructed ponds: four species per sampling event at Ankney Pond and West Feed Pond and no more than two species at Kozac Pond and Thompson Pond. At all ponds, piscivore species were more frequently encountered in the summer.

In the summer of 2015, there were 66% more fish seined from Ankney Pond than in 2014, whereas 51% fewer fish were collected from Kozac Pond. Although more individuals were

seined from Ankney Pond in 2015, species richness was 20% lower than in 2014. Alternatively, species diversity in Kozac Pond was 25% higher. Lake Chubsucker and Pugnose Shiner were found in Ankney Pond and Warmouth was found in Kozac Pond. No previously undetected species were detected from either pond.

Spring fish assemblages were significantly different among ponds ($F=1.83$, $df=4$, $p=0.045$), but not between years ($p=0.22$). The reference pond assemblage changed very little between 2013 and 2014, whereas, the created ponds did have changes in their assemblages between the two years (Figure 2). West Feed Pond had a similar assemblage to the reference ponds in 2013, and all other ponds had different fish assemblages. The reference ponds had a greater abundance of Blackchin Shiner and Pugnose Shiner than created Ankney Pond, Kozac Pond, and Thompson Pond.

Fish assemblage composition based on the summer abundance of fishes in each pond was significantly different among ponds ($F=1.65$, $df=4$, $p=0.05$) and among sampling years ($F=2.43$, $df= 2$, $p=0.001$). All of the created ponds differed in composition compared to the reference sites (Figure 3). This was based on differences in species abundance among ponds. West Feed Pond had larger abundances of Black Bullhead (*Ameiurus melas*), Brown Bullhead (*Ameiurus nebulosus*), Grass Pickerel, and Central Mudminnow (*Umbra limi*) compared to the other ponds. Ankney Pond exhibited differences in assemblage composition as it had a high abundance of Brook Silverside (*Labidesthes sicculus*), Blackchin Shiner, and Tadpole Madtom (*Noturus gyrinus*). Both Thompson Pond and Kozac Pond had lower abundances of many species compared to the other ponds. Similar to the spring, the fish assemblages in the created ponds differed between years, whereas, reference ponds showed much less variation in their communities, 2012–2014.

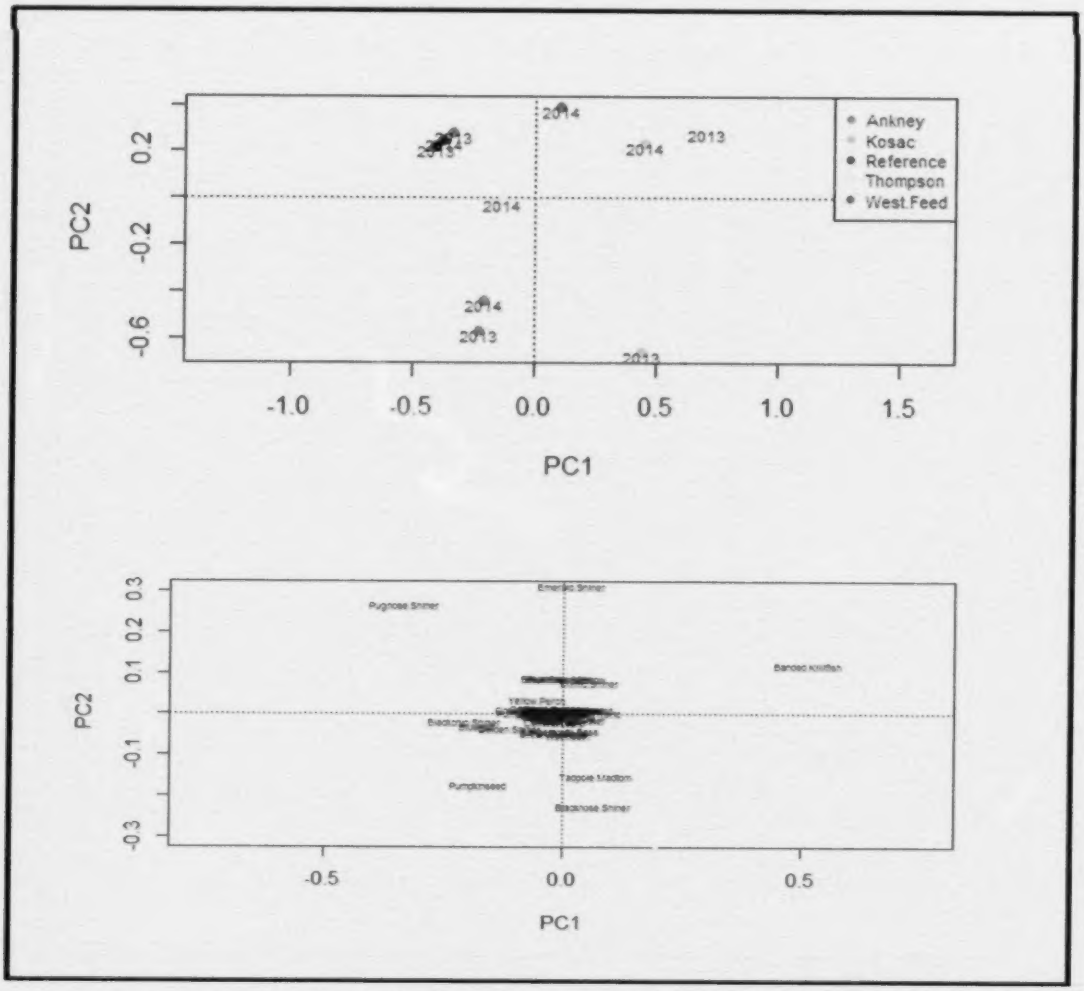

Figure 2. Ordination plot comparing fish assemblages in each pond, spring 2013–2014, based on species abundance data. Note that there is a difference in scales between the site and species plots. There was a significant difference in assemblage composition among ponds (p=0.049), but not among years (p=0.221).

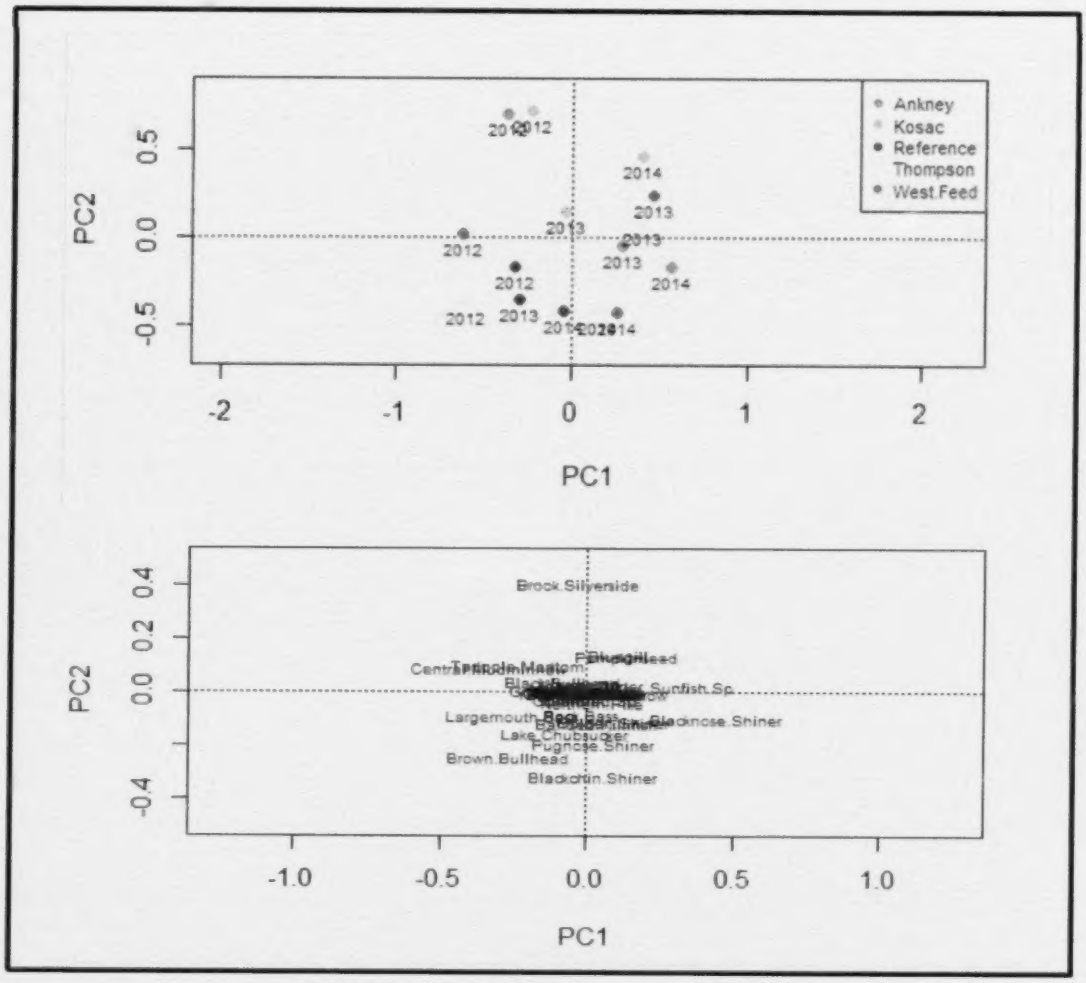

Figure 3. Ordination plot comparing fish assemblages in each pond, summer 2012–2014, based on species abundance data. Note that there is a difference in scales between the site and species plots. There was a significant difference in assemblage composition among ponds (p=0.05) and years (p=0.001).

ISOLATED PONDS

Ponds 4 and 6 were initially isolated from Long Point Bay and then connected in fall 2015. In 2015, 20 sites were sampled at Ponds 4 and 6. This resulted in fish collection data associated with 300 seine hauls. A total of 8,846 fishes were caught, representing 24 species. The most commonly occurring species were Blacknose Shiner (*Notropis heterolepis*), Bluegill, Bluntnose Minnow (*Pimephales notatus*), Largemouth Bass, Pumpkinseed and Yellow Perch. These species made up 65% of the total number of fishes caught. Species at risk fishes were detected in isolated ponds. Pond 6 contained Grass Pickerel and Pugnose Shiner, and Pond 4 contained Pugnose Shiner and Warmouth. Fish species at risk made up <1% of the total catch.

There were significant differences in fish assemblage composition between the ponds (F=2.96, df= 1, p=0.001) and among the three seasons (F=1.95, df=2, p=0.03) (Figure 4). Differences between ponds reflected the large numbers of Blacknose Shiner, Bluegill, and Bluntnose Minnow seined from Pond 4, and the large numbers of Largemouth Bass seined from Pond 6. Seasonal differences within ponds reflected variation in the relative abundance of Blacknose Shiner, Bluegill, Largemouth Bass, Pumpkinseed, and Yellow Perch. Once connected to Long Point Bay, there was an increase in the number of species in Pond 4, but not in Pond 6. In Pond 6, more fishes were captured in the fall compared to the summer (Table 5).

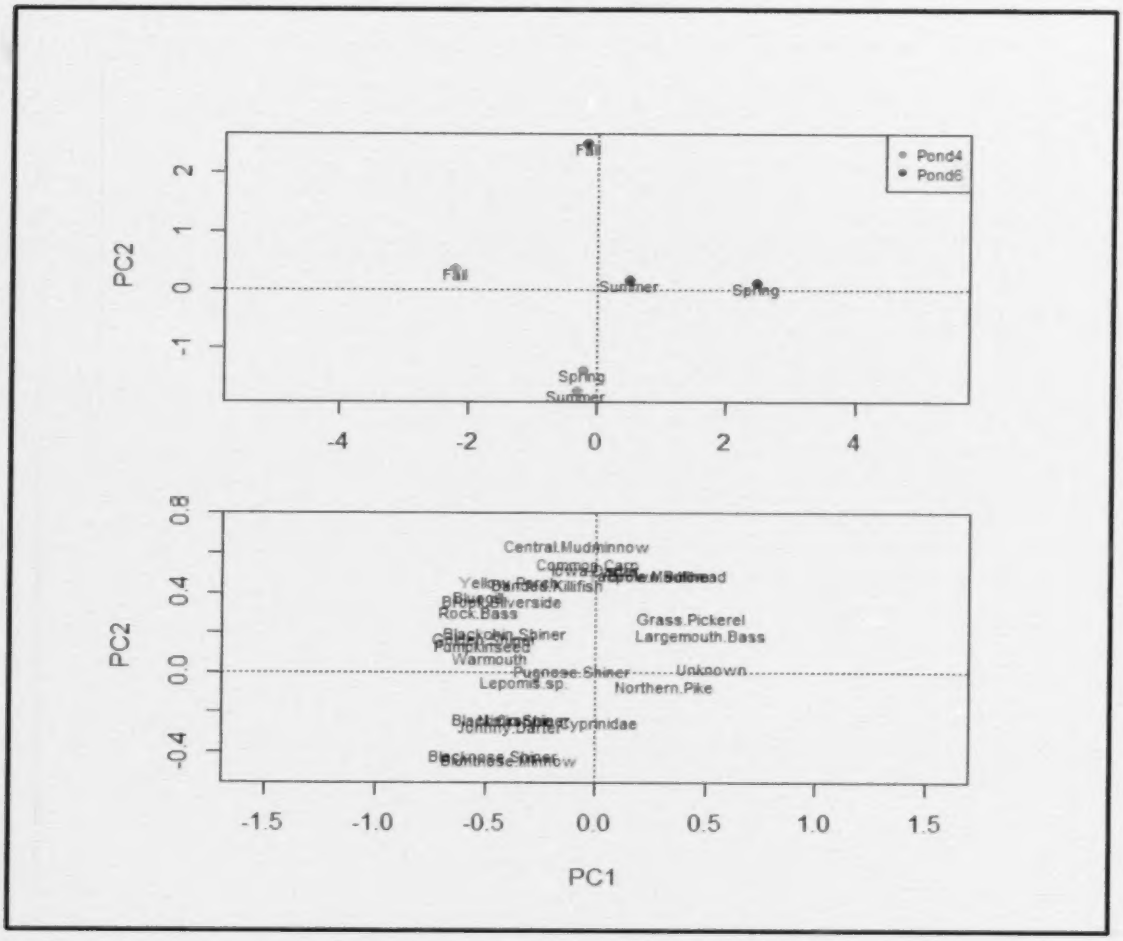

Figure 4. Ordination plot comparing fish assemblages in Pond 4 and Pond 6 in the spring, summer, and fall, based on species abundance data. Note that there is a difference in scales between the site and species plots. There was a significant difference in assemblage composition between ponds (p=0.0014) and among seasons (p=0.033).

Table 5. Summary of all fishes captured at each isolated pond during each season, including number of fishes, number of species, total number of species, and number of species at risk fishes at each pond.

Pond	Sampling event	No. of fishes	No. of species	No. of species at risk	Total no. of species
Pond 4	Spring 2015	593	13	1	23
	Summer 2015	2887	13	1	
	Fall 2015	2235	21	3	
Pond 6	Spring 2015	1330	13	2	22
	Summer 2015	490	18	31	
	Fall 2015	1311	18	1	

HABITAT

Vegetation differed among ponds but little change occurred over time. In both spring and summer, the percentage of submerged vegetation, floating vegetation, and open water was different among ponds (Tables 6 and 7). In the summer, both newly created Ankney Pond and Kozac Pond had significantly less submerged vegetation than Reference Pond 1 ($p < 0.001$). Ankney Pond and Kozac Pond both had significantly more open water than Reference Pond 1 ($p < 0.001$). In the spring, there was significantly less submerged vegetation at Kozac Pond than Reference Pond 1 and more open water ($p=0.016$, $p=0.012$). There were no differences in the amounts of submerged vegetation or open water found in Ankney Pond and Kozac Pond, and Reference Pond 2. Thompson Pond had significantly more submerged vegetation than Reference Pond 2 ($p < 0.001$). Overall, Reference Pond 1 and West Feed Pond had the greatest percentage of vegetation whereas newly created Ankney Pond and Kozac Pond had the most open water, and all of the ponds had more open water in the spring when compared to the summer.

Submerged vegetation was consistently the dominant type of vegetation among all ponds. During the summer of 2014, dominant species identified for each pond were:

1. Ankney Pond – *Chara* spp.;
2. Kozac Pond – bladderwort (*Utricularia* spp.) and common reed;
3. Thompson Pond – *Chara* spp.;
4. West Feed Pond - bladderwort;
5. Reference Pond 1 – Canadian pondweed (*Elodea canadensis*) and coontail (*Ceratophyllum demersum*); and,
6. Reference Pond 2 – *Chara* spp. and Canadian pondweed.

In the spring, water quality was different among ponds and between the two years (Table 8). Water temperature was, on average, 2.9 °C lower in West Feed Pond compared to the other ponds. Conductivity and dissolved oxygen were both variable among all of the ponds. There was also a wide range in turbidity, but both newly created Ankney Pond and Kozac Pond were significantly more turbid than Reference Pond 1 ($p<0.001$). Spring turbidity values at the new ponds were higher than measurements taken by DFO at various inner Long Point Bay nearshore sites outside of the Crown Marsh study area between 2012 and 2014 (mean NTU = 4.8, n = 56 sites). Inner Long Point Bay turbidity measurements were taken during a fieldwork unrelated to the Crown Marsh study.

In the summer, water quality measurements were significantly different among ponds but not over time. Thompson Pond had a significantly lower water temperature compared to Reference

Pond 1 and 2 ($p=0.004$, $p<0.001$). Reference Pond 1 had a lower conductivity compared to the created ponds, whereas, Reference Pond 2 had a higher conductivity. Dissolved oxygen was relatively similar among all ponds except for West Feed Pond having a significantly higher dissolved oxygen than Reference Pond 2 ($p=0.04$). Turbidity was relatively similar between ponds in the summer but Reference Pond 2 was seen to have the lowest turbidity (mean 2.28 NTU) out of all the ponds and Ankney Pond had the greatest (mean 14.0 NTU). Summer turbidity values at the new ponds were similar to measurements taken by DFO at various inner Long Point Bay nearshore sites outside of the Crown Marsh study area between 2012 and 2014 (mean NTU = 12.0, n = 128 sites).

Based on the 2012 temperature data that extends into January 2013, water temperature in all ponds ranged from ≤ 0 to 36.5 °C (Figure 5). All ponds show similar trends in temperature. Similarly, the channels show comparable temperature trends and also decreased to 0 °C (Figure 6).

In both the spring and the summer, the ponds created in the past 6 years (Ankney Pond, Kozac Pond, and Thompson Pond) were much shallower than the older created pond West Feed and the Reference Ponds. Pond depth remains quite constant over each sampling event (Figure 7). In 2012, all of the created ponds were shallow, and Kozac Pond, Thompson Pond, and West Feed Pond contained no water at some points. In 2013, depth appeared to be slightly greater and all ponds remained flooded throughout the sampling period. Water depth was greater in 2013 and 2014 than in 2012, but in both 2013 and 2014 the depth began to decrease in November. West Feed Pond, Reference Pond 1, and Reference Pond 2 channels appear to be deeper than their ponds in both 2013 and 2014 (Figure 8). The channel to Ankney Pond tended to be the shallowest, and on some occasions, is nearly dry.

Based on the WFI, all of the ponds are in a healthy condition as the values are above 3.25. Habitat quality does improve over the years sampling took place as values were lowest in 2012 and increased throughout 2013 and 2014 (Table 9). Newly created Ankney Pond and Reference Pond 1 have the best quality habitat as their overall WFI values were 4.01 and 4.04, respectively.

Table 6. Among-pond comparison of vegetation cover based on 2012–2014 data. The July and August sampling events are represented by 2012A and 2012B, respectively. Values in bold represent the dominant vegetation type.

	2012A				2012B				2013				2014			
	Emergent (%)	Floating (%)	Submerged (%)	Open Water (%)	Emergent (%)	Floating (%)	Submerged (%)	Open Water (%)	Emergent (%)	Floating (%)	Submerged (%)	Open Water (%)	Emergent (%)	Floating (%)	Submerged (%)	Open Water (%)
Ankney Pond	14	0	**49.5**	36.5	6	0	**56**	28	10.5	0	**48.5**	41	10	0	**67**	23
Kozac Pond	4.2	0	**56.7**	39.2	2.5	0	**49.5**	48	19	0	**46.5**	34.5	17.5	0	34.5	**48**
Thompson Pond	14	6.3	**78.8**	1.3	13.6	4.1	**77.3**	5	5.2	8.3	**77.5**	9	4.5	1	**93**	1.5
West Feed Pond	20	11	**60.5**	9	9	2.5	**84**	4	3.5	11	**53.5**	27.8	10	2.5	**70**	17.5
Reference Pond 1	4.5	11	**85**	0	1.7	3.3	**92.8**	2.2	13.5	14	**72.5**	0	10.5	11	**78**	1
Reference Pond 2	7.5	2.5	**58.5**	31.5	8.2	7.3	**54.6**	20.9	5.6	6.1	**52.8**	35.6	9.4	2.2	**59.4**	28.9

Table 7. Summary of differences between habitat variables among ponds and years. An ANCOVA was used to determine if there were significant differences or no difference (N.S.) found. df = degrees of freedom.

	Summer		Spring	
Habitat variable	**Ponds (df = 5)**	**Years (df = 2)**	**Ponds (df = 5)**	**Years (df = 1)**
Submerged Vegetation	Yes (F= 15.3, p<0.001)	N.S.	Yes (F=2.7, p=0.02)	N.S.
Emergent Vegetation	N.S.	N.S.	N.S.	Yes (F=5.2, p=0.02)
Floating Vegetation	Yes (F=6.7, p<0.001)	N.S.	Yes (F= 5.0, p<0.001)	N.S.
Open Water	Yes (F=18.7, p<0.001)	N.S.	Yes (F= 2.6, p=0.031)	N.S.
Water Temperature	Yes (F=9.1, p<0.001)	Yes (F=220.8, p<0.001)	Yes (F=19.3, p<0.001)	Yes (F=11.2, p=0.001)
Turbidity	Yes (F=8.5, p<0.001)	N.S.	Yes (F=25.7, p<0.001)	Yes (F=52.7, p<0.001)
Conductivity	Yes (F=19.9, p<0.001)	Yes (F=9.9, p=0.002)	Yes (F=36.6, p<0.001)	Yes (F=412.9, p<0.001)
Dissolved Oxygen	Yes (F=3.3, p=0.007)	Yes (F=17.0, p<0.001)	Yes (F=48.5, p<0.001)	Yes (F=52.9, p<0.001)
Water Depth	Yes (F=156.9, p<0.001)	Yes (F=130.3, p<0.001)	Yes (F=138.4, p<0.001)	Yes (F=269.6, p<0.001)

Table 8. Among-pond comparison of spring and summer mean water quality measurements and pond depth, based on 2012–2014 data. Cond. = conductivity, DO = dissolved oxygen; Temp. = temperature.

	Spring					Summer				
	Water temp. (°C)	Turbidity (NTU)	Cond. (µS/cm)	DO (mg/L)	Depth (m)	Water temp. (°C)	Turbidity (NTU)	Cond. (µS/cm)	DO (mg/L)	Depth (m)
Ankney Pond	22.15	32	383.55	6.42	0.39	24.36	14.01	355.55	7.39	0.46
Kozac Pond	21.8	28.15	307.25	9.25	0.33	24.18	6.67	363.85	6.52	0.21
Thompson Pond	20.63	9.36	389.1	9.13	0.37	20.99	6.67	349.05	7.8	0.46
West Feed Pond	17.82	16.53	335.5	7.34	0.59	22.95	13.37	345.8	8.31	0.35
Reference Pond 1	21.5	8.32	350.4	6.51	0.78	23.34	10.05	292.7	7.75	1.05
Reference Pond 2	20.19	22.98	373.45	5.61	0.6	24.56	2.28	386.8	6.48	0.85

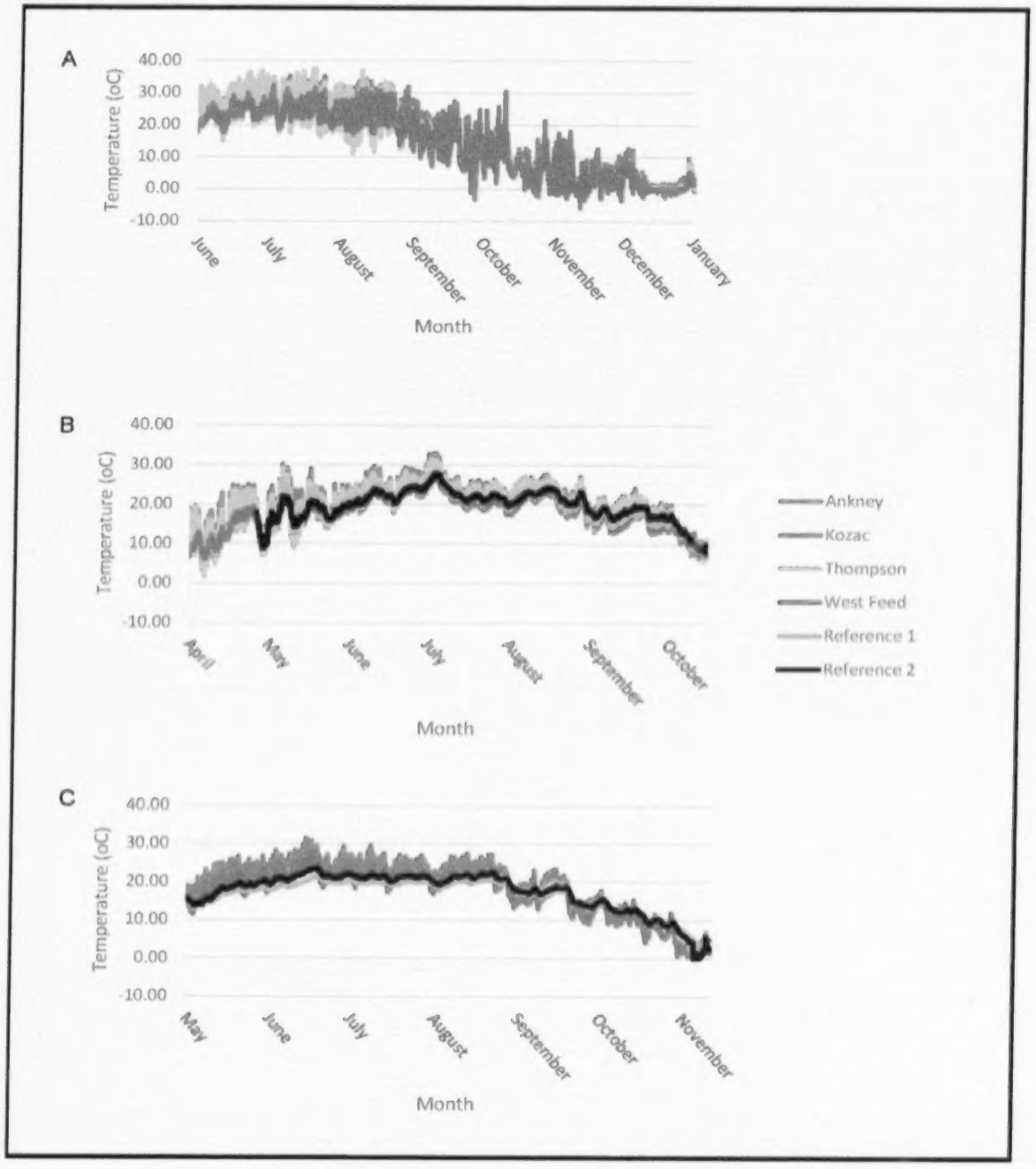

Figure 5. Water temperature in ponds throughout (A) 2012, (B) 2013, and (C) 2014. In 2012, only the created pond temperatures were recorded, whereas, in 2013 and 2014, Reference Pond temperatures were also recorded. Recording commenced in January 2012, in October 2013, and in November 2014.

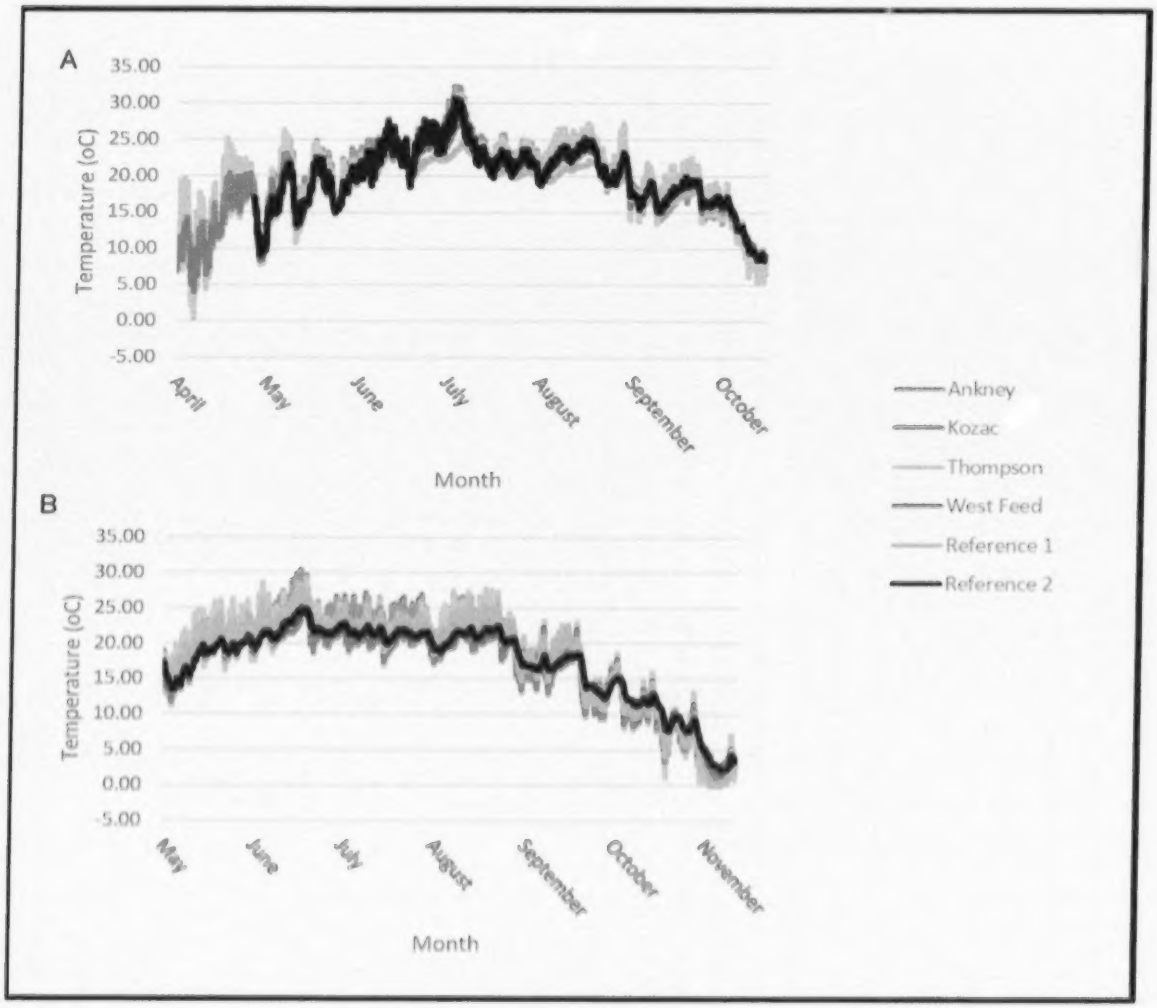

Figure 6. Channel water temperature throughout (A) 2013, and (B) 2014. Water temperatures were recorded until October in 2013 and November in 2014.

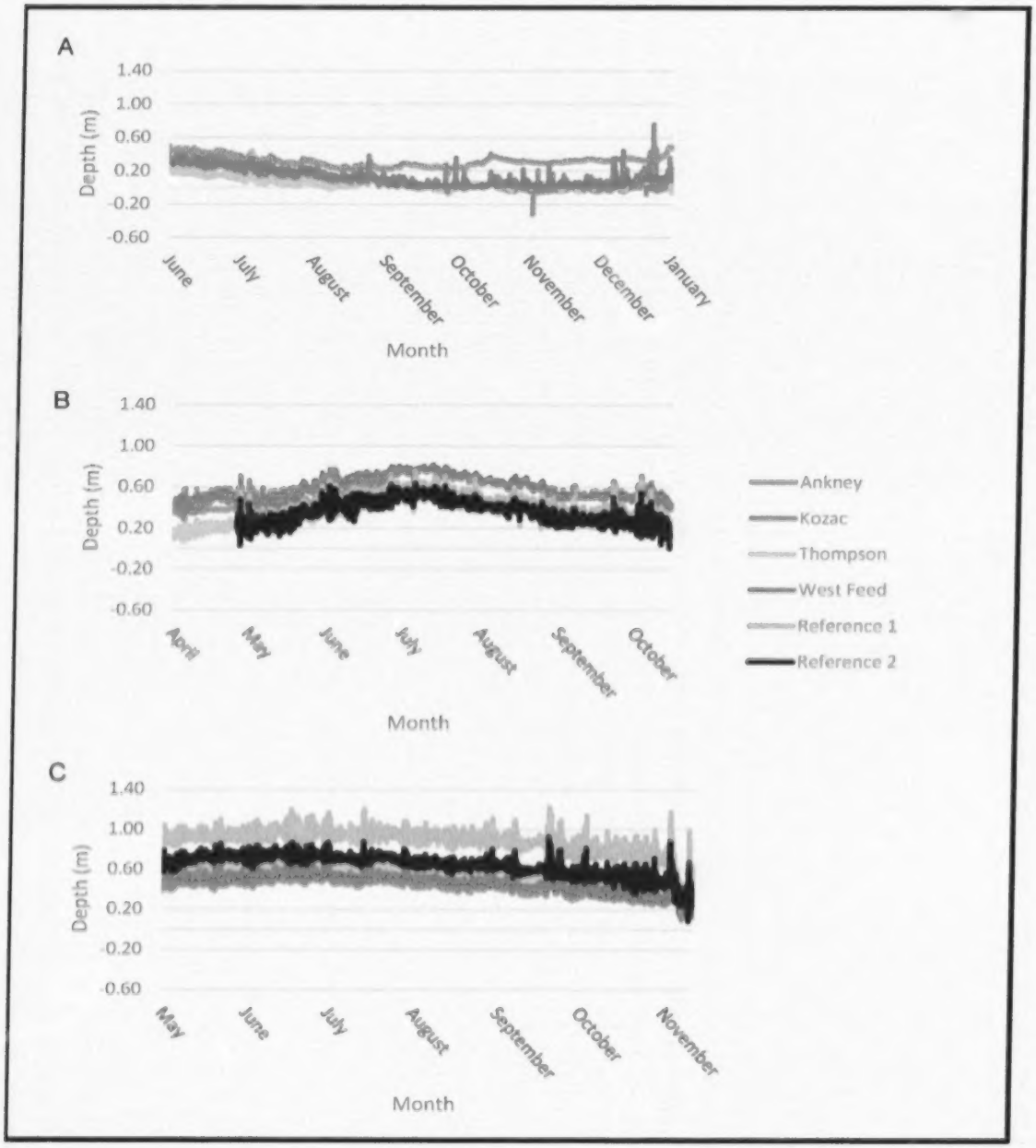

Figure 7. Depth measurements for each pond throughout (A) 2012, (B) 2013, and (C) 2014. In 2012, only the created ponds temperatures were successfully recorded whereas Reference Pond temperatures were also recorded in 2013 and 2014. Recording commenced in January 2012, in October 2013, and in November 2014.

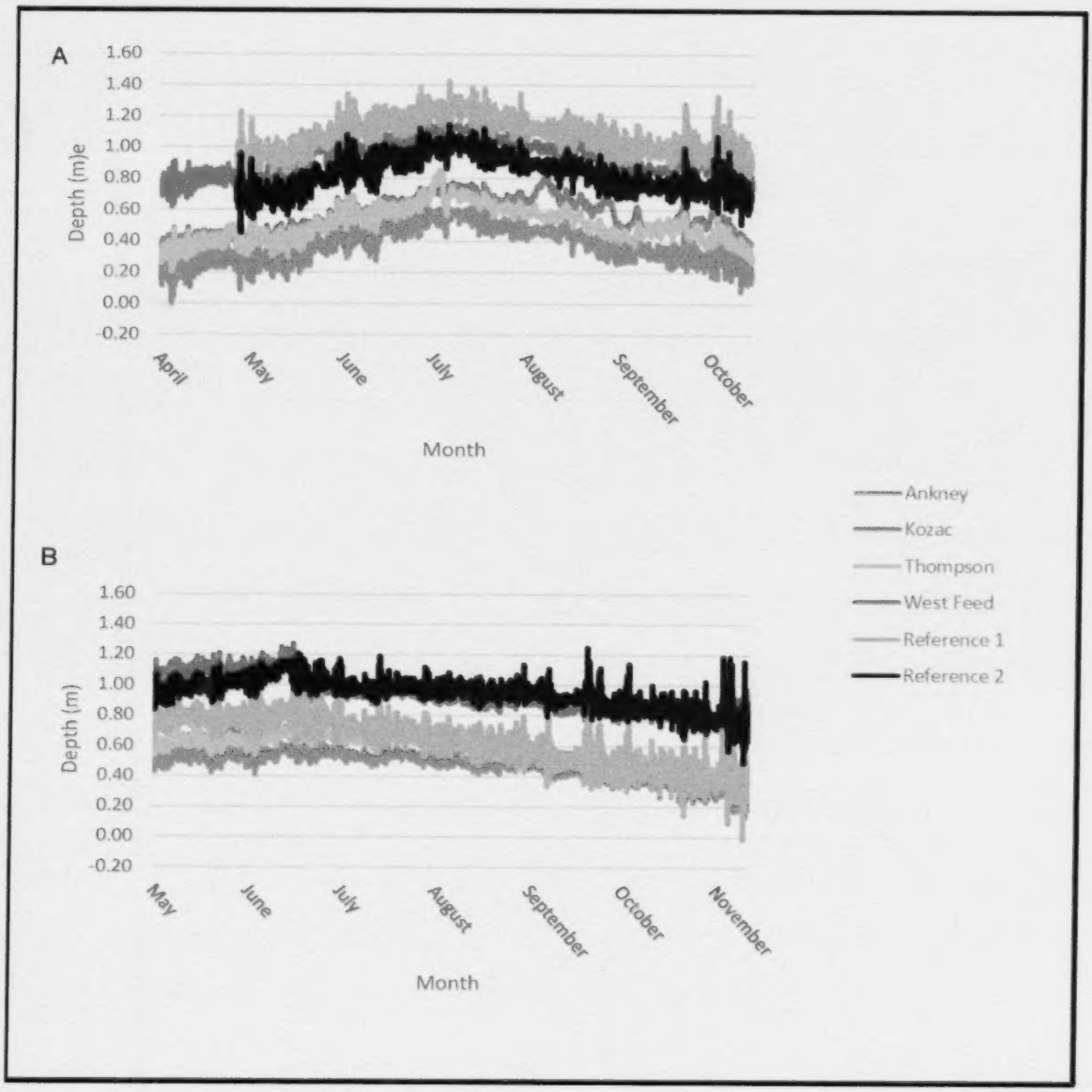

Figure 8. Depth measurements in channels throughout 2013 (A), and 2014 (B). Depths were recorded until October in 2013 and November in 2014.

Table 9. Wetland fish index (WFI) values for each pond over the six sampling events.

	July 2012	August 2012	Spring 2013	Summer 2013	Spring 2014	Summer 2014
Ankney Pond	3.69	4.02	3.91	4.08	3.99	4.07
Kozac Pond	3.56	3.67	4.14	3.71	3.94	3.72
Thompson Pond	3.63	3.98	4.01	3.8	3.84	3.95
West Feed Pond	3.58	3.62	3.78	3.66	4.02	3.88
Reference Pond 1	3.96	4.04	4.13	4.15	4.21	4.06
Reference Pond 2	3.63	3.8	4.06	3.29	3.94	3.86

DISCUSSION

SPECIES AT RISK FISHES PRESENT

Which fish species are present (with focus on species at risk) in created open-water wetland habitats of Crown Marsh from spring to fall?

Species at risk fishes captured were Grass Pickerel, Lake Chubsucker, Pugnose Shiner, and Warmouth. Throughout the study no Spotted Gar were captured. Since 1947, only 17 Spotted Gar have been recorded in Long Point Bay, and it has been suggested that Spotted Gar reproduction may not be successful in this area (Glass and Mandrak 2014). Eastern Sand Darter was not captured either. Fine sand habitats preferred by the Eastern Sand Darter were not present in the study ponds.

Kozac Pond and Ankney Pond, created in 2012, supported the four fish species at risk at various times during sampling, but most of the species at risk were found in very low abundances. Kozac Pond had a total of 11 species at risk individuals and Ankney Pond had 79 individual species at risk. Grass Pickerel, Lake Chubsucker, and Pugnose Shiner were found in Thompson Pond and West Feed Pond, but no Warmouth were captured. In all the ponds, Pugnose Shiner was found in greatest abundance in the spring, but these numbers substantially decreased in the summer. Little is known about Pugnose Shiner spawning, but it is thought that spawning may occur mid-May to July (COSEWIC 2013). Migration into the ponds to spawn could account for the large abundances of Pugnose Shiner in the spring. It is unknown if the decrease in Pugnose Shiner in the summer is due to movement of the fish, predation, or undesirable pond habitat conditions resulting in mortality. Grass Pickerel, Lake Chubsucker, and Warmouth were found in greater abundances in the summer compared to the spring.

FISH ASSEMBLAGES

Compare the composition of fish assemblages present in created wetland habitats of different ages to reference sites.

Fish assemblages in created ponds were different from one another and the reference ponds (for both spring and summer). In spring and summer, there was a greater abundance of Pugnose Shiner in reference ponds compared to the created ponds. There were more Bluegill (*Lepomis macrochirus*) and Pumpkinseed (*Lepomis gibbosus*) in created ponds in the summer compared to the reference ponds. At all the created ponds, there was a shift in summer assemblage composition from 2012 to 2013 and 2014. In 2012, there was a greater abundance of Brown Bullhead, Central Mudminnow, and Largemouth Bass, whereas, in 2013 and 2014, more Blackchin Shiner and sunfish species were present. Fish assemblages in created ponds were not stable over time, they changed each year. Unlike created ponds, fish assemblages in

reference ponds were more stable from 2012 to 2014. This has been seen in other systems as natural wetlands in east-central Arkansas and in east-central Florida had a more stable and developed habitat than newly created wetlands in the same area (Langston and Kent 1997; Leao et al. 2004).

YOY and juvenile fishes were found in all ponds, which indicates all ponds are used as spawning and nursery habitats. All of the ponds had assemblages that included some piscivorous species. Reference ponds had a greater number of piscivorous species than created ponds, and the frequency of occurrence of piscivores was greater in summer compared to spring.

HABITAT CONDITION

Differences in habitat condition between habitats of different age, and across years of the study compared to reference sites.

There was high variability in habitat condition among ponds. The greatest amount of open water was present in the two newly created ponds. As the ponds were recently dredged, more complex vegetative habitat had not yet developed. The dominant substrate in the newly-created ponds is sand, which may not be suitable for the rapid re-establishment of aquatic macrophytes. Both reference ponds had more submerged vegetation compared to the newly created ponds.

Newly created ponds were more turbid than reference ponds. Water temperature, dissolved oxygen, and conductivity all varied among ponds and seasons. Thompson Pond in August 2014 and Kozac Pond in July 2012 had very low dissolved oxygen concentrations (2.6 mg/L and 1.5 mg/L, respectively). Dissolved oxygen concentrations <3 mg/L can be detrimental or lethal to most fishes (Canadian Council of Ministers of the Environment 1999). Therefore, summertime pond habitats may be physiologically stressful for some fish species. The three ponds most recently created, Ankney Pond, Kozac Pond, and Thompson Pond, were much shallower than the reference ponds and West Feed Pond created in the 1970s.

ASSESSMENT OF CREATED HABITAT

Assess the value of created habitats as sources or sinks to species at risk fishes; are these habitats a net benefit?

Crown Marsh is 560 ha in size, of which 84 ha was open water in 2014. The amount of open water habitat had increased from 37.52 ha in 2006 due to the removal of common reed and cattail stands. The long term goal for Crown Marsh is to create a hemi-marsh environment containing a 50:50 ratio of open water habitat to emergent vegetation (E. Cleland, OMNRF, pers. comm.). To determine the value of created ponds for species at risk fishes, the following were considered:

1. quantity and quality of habitat;
2. connectivity of the ponds to Long Point Bay; and,
3. presence of YOY and juvenile fishes.

Recovery potential assessments for Pugnose Shiner (DFO 2010) and Lake Chubsucker (DFO 2011) predict that to support minimum viable population (MVP) sizes, a minimum habitat area of 5 ha and 100 ha, respectively, is required. Individually, Ankney Pond and Kozac Pond do not provide the minimum amount of habitat required. However, ponds are not isolated from the rest of Crown Marsh and the potential value of created ponds can also be assessed by considering the long-term restoration goal. The quantity of open-water habitat in Crown Marsh is currently

below the amount required for a viable Lake Chubsucker population. However, if the restoration target of a 50:50 ratio of open water to emergent vegetation target is reached (and these habitats are connected), then enough habitat would be present in Crown Marsh to support MVPs for both species.

The wetland fish index (WFI) was developed to determine the ecological condition of Great Lakes coastal wetland quality based on species-specific tolerances to degradation (Seilheimer and Chow-Fraser 2006). Based on the WFI values, Crown Marsh ponds are not degraded as all values are greater than 3.25. Reference Pond 1 and Ankney Pond have the highest WFI scores at 4.04 and 4.02, respectively. Thompson Pond and West Feed Pond had the lowest scores of 3.84 and 3.81; still well above the 3.25 threshold.

Connectivity of wetlands to larger bodies of water increases fish species richness in wetlands (Theiling et al. 1999; Kowalski et al. 2014). Pond 4 and Pond 6 in Crown Marsh were connected to Long Point Bay in fall 2015. A significant difference in fish assemblages were found between the spring and summer sampling, when the ponds were isolated, to the fall sampling when the ponds were connected. Pond 4 had a greater species richness after being connected to Long Point Bay and Pond 6 had a greater abundance of fishes. This indicates the connectivity does play a role in the assemblages that form in the ponds. All of the created ponds were connected to Long Point Bay, and water levels in the channels indicated that they stay submerged though the year. This allows for fishes to migrate to the wetlands for spawning, and it ensures fishes are able to exit the ponds if habitat conditions become unfavourable.

The importance of lower Great Lakes coastal wetland habitats as fish spawning and nursery habitat is well documented (Stephenson 1990; Leslie and Timmons 1997). In the summer, YOY and juveniles of 23 species were seined from newly constructed ponds, including four fish species at risk. These results indicate that the newly constructed ponds function as nursery habitat, and potentially spawning habitat. The collection of a spawning-ready female Lake Chubsucker from West Feed Pond (spring 2014) indicates that spawning by fish species at risk does occur in older constructed ponds.

Ecological Trap Assessment

Ecological traps can be an unintended consequence of habitat restoration activities (Jeffres and Moyle 2012). Traps occur when individuals select restored or created habitats, and the value of these habitats for survival and reproduction is low. The result of altered habitat selection could be population declines or sinks (Jeffres and Moyle 2012). If newly constructed ponds are ecological traps, it could have a negative effect on the recovery of local fish species at risk populations within Crown Marsh and the inner bay of Long Point. In this study, direct assessments of spawning success or mortality rates in Ankney Pond and Kozac Pond were not undertaken. However, some potential concerns that may result in an ecological trap should be identified, as these can inform the design of new ponds in Crown Marsh. Low water levels, high water temperatures, low dissolved oxygen, and a lack of structural complexity in the ponds are all potential concerns.

If water levels drop such that connections to channels in Crown Marsh are lost, fishes would become isolated in the ponds. Isolation can pose a threat to fish species at risk if conditions become physiologically stressful. Extremely high water temperatures or low dissolved oxygen can lead to fish kills in isolated pools (Tramer 1977; Sargent and Galat 2002). In the summer, temperatures have reached 35 °C in the ponds and dissolved oxygen has been as low as 1.45 mg/L, indicating that harsh conditions occur. Shallower ponds such as Kozac Pond are at greater risk of ice forming all the way to the bottom in the winter. If the ponds froze only at the surface, a depletion of dissolved oxygen levels may occur, which would increase over winter mortality. Based on the level logger data, many of the ponds experience low water levels and

maybe dry at various times. However, level loggers were not necessarily placed in the deepest part of the pond, so recorded depths of 0 m may only indicate extremely low water depths across a portion of the pond.

An ecological trap could also exist in new ponds as habitats are not structurally complex. Aquatic macrophyte beds provide habitats that protect small-bodied fishes or early life-stages vulnerable to predation, and this cover can appreciably improve survival (Savino and Stein 1982; Werner and Hall 1988). Over the three years of this study, there was significantly less submersed macrophyte cover at new ponds than the reference sites. Therefore, small-bodied fish species at risk (e.g., Pugnose Shiner) could be more vulnerable to predation in new ponds. Seining data does indicate that comparatively fewer piscivores were present in Ankney Pond and Kozac Pond; which may offset the lack of cover.

MAXIMIZING BENEFITS FOR SPECIES AT RISK FISHES

Approaches that should be considered in maximizing the value of created habitats for species at risk fishes

To ensure the maximum value of ponds for fish species at risk, ponds should be designed to:

1. provide refugia when habitat conditions are physiological stressful, and
2. support the viability of populations within inner Long Point Bay.

Two primary considerations are water depth and connectivity to channels.

Shallow ponds are expected to be more susceptible to warming in summer, lowering of dissolved oxygen, and complete freezing in the winter. The Crown Marsh created ponds are relatively shallow with mean depths between 0.21 m and 0.59 m. Creating a depth gradient in each pond with the deepest portion of the pond at connections with navigation channels would reduce the risk of stranding when lake levels are extremely low.

It is important to have connecting channels to Long Point Bay and the other ponds, and to maintain open access to these channels from the ponds. Multiple connections out of the ponds would allow fishes to migrate out of ponds when habitat conditions are stressful. High connectivity among the variety of Crown Marsh habitats would also increase the likelihood that new ponds would contribute to recovery targets for Lake Chubsucker (i.e., MAVP of 100 ha).

Wetland fish species at risk are dependent on abundant and complex aquatic macrophyte beds. As observed in Ankney and Kozac ponds, the establishment of this habitat type after dredging has not been rapid. To promote macrophyte growth, extensive maintenance works in ponds should be avoided. If ongoing monitoring indicates the re-establishment of aquatic macrophytes is limited, the appropriateness of native seed bank transfer from other inner Long Point Bay locations should be evaluated.

KNOWLEDGE GAPS

Field sampling provided important information on the habitat characteristics and fish assemblages (include the presence of fish species at risk) in constructed Crown Marsh ponds. However, research activities did not attempt to measure population-level parameters that would allow direct inferences regarding whether ponds function as population sinks. An improved understanding of the spatial dynamics of fish species at risk populations within the complex of Crown Marsh habitats would require characterizing:

1. the composition of fish assemblages within navigation channels (likely source populations);

2. the movement patterns (and distances) of individuals among different habitats within Crown Marsh, and between other inner Long Point Bay habitats and Crown Marsh;
3. the use of constructed ponds as over-wintering habitats, and likelihood of ice-formation to the bottom of ponds;
4. the variation in prevalence of fish species at risk in piscivore diets among habitats; and,
5. the abundance of larval and juvenile fishes to measure spawning success.

A conceptual spatially-explicit population model for fish species at risk in Crown Marsh would help to direct further research, and help to identify testable hypotheses.

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APPENDIX

Table A.1. List of fishes caught in Crown Marsh 2012–2014. Common and scientific names according to Page et al. (2013).

Scientific name	Common name
Ambloplites rupestris	Rock Bass
Ameiurus melas	Black Bullhead
Ameiurus natalis	Yellow Bullhead
Ameiurus nebulosus	Brown Bullhead
Amia calva	Bowfin
Carassius auratus	Goldfish
Cyprinella spiloptera	Spotfin Shiner
Cyprinus carpio	Common Carp
Erimyzon sucetta	Lake Chubsucker
Esox americanus vermiculatus	Grass Pickerel
Esox lucius	Northern Pike
Etheostoma exile	Iowa Darter
Etheostoma nigrum	Johnny Darter
Fundulus diaphanus	Banded Killifish
Labidesthes sicculus	Brook Silverside
Lepisosteus osseus	Longnose Gar
Lepomis gibbosus	Pumpkinseed
Lepomis gulosus	Warmouth
Lepomis macrochirus	Bluegill
Micropterus salmoides	Largemouth Bass
Notemigonus crysoleucas	Golden Shiner
Notropis anogenus	Pugnose Shiner
Notropis atherinoides	Emerald Shiner
Notropis heterolepis	Blacknose Shiner
Notropis heterodon	Blackchin Shiner
Notropis hudsonius	Spottail Shiner
Notropis volucellus	Mimic Shiner
Noturus gyrinus	Tadpole Madtom
Osmerus mordax	Rainbow Smelt
Perca flavescens	Yellow Perch
Pimephales notatus	Bluntnose Minnow
Pimephales promelas	Fathead Minnow
Pomoxis nigromaculatus	Black Crappie
Umbra limi	Central Mudminnow

Table A.2. Number of fish species at risk seined from created and natural ponds in 2012.

	2012							
	July				August			
	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner
Ankney Pond	0	8	0	0	2	9	12	0
Kozac Pond	0	4	0	0	0	1	1	0
Thompson Pond	5	0	0	0	9	2	0	0
West Feed Pond	6	11	0	0	9	12	0	0
Reference Pond 1	0	1	1	42	7	0	2	104
Reference Pond 2	4	6	0	0	45	7	2	0

Table A.3. Number of fish species at risk seined from created and natural ponds in 2013.

	2013							
	Spring				Summer			
	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner
Ankney Pond	0	0	1	7	3	1	0	4
Kozac Pond	1	0	1	0	1	0	0	0
Thompson Pond	0	0	0	17	0	0	0	3
West Feed Pond	1	0	0	194	0	0	0	15
Reference Pond 1	0	0	0	448	13	1	1	40
Reference Pond 2	0	0	0	27	0	0	0	0

Table A.4. Number of fish species at risk seined from created and natural ponds in 2014.

	2014							
	Spring				Summer			
	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner	Lake Chubsucker	Grass Pickerel	Warmouth	Pugnose Shiner
Ankney Pond	0	0	0	9	0	0	0	7
Kozac Pond	0	0	0	1	0	0	1	0
Thompson Pond	0	0	0	7	3	0	0	184
West Feed Pond	3	0	0	41	20	0	0	2
Reference Pond 1	2	2	1	623	40	5	1	7
Reference Pond 2	0	0	0	26	8	11	0	0

Table A.5. Summary of key fish and habitat findings among ponds.

		Fishes		Habitat	
Pond	**Year created**	**Species at risk**	**Fish assemblage**	**Aquatic macrophytes**	**Water chemistry**
Ankney Pond	2012	Contained all four species at risk at both adult and young-of-the-year life stages.	Fish assemblage contained up to four predatory species in a given sampling event. The fish assemblage varied year to year.	Submerged vegetation was the dominant macrophyte. Consisted of significantly more open water than Reference Pond 1, Thompson Pond, and West Feed Pond. Little change in vegetation 2012–2014.	Significantly higher turbidity compared to older created ponds and reference ponds.
Kozac Pond	2012	Contained all four species at risk, but they were found in very low abundance.	Fish assemblage contained up to two predatory species in a given sampling event. The fish assemblage varied year to year.	Submerged vegetation was the dominant macrophyte. Consisted of significantly more open water than Reference Pond 1, Thompson Pond, and West Feed Pond. Little change in vegetation 2012–2014.	Significantly higher turbidity compared to older created ponds and reference ponds.
Thompson Pond	2010	Contained only three species at risk, Warmouth were never caught.	Fish assemblage contained up to two predatory species in a given sampling event. The fish assemblage varied year to year.	Submerged vegetation was the dominant macrophyte (>75%). Little change in vegetation 2012–2014.	Lower water temperature in the summer compared to reference ponds.
West Feed Pond	circa 1970s	Contained only three species at risk, Warmouth were never caught.	Fish assemblage contained up to six predatory species in a given sampling event. The fish assemblage varied year to year.	Submerged vegetation was the dominant macrophyte. Had the most variation in vegetation 2012–2014 among all ponds	Higher dissolved oxygen conc. compared to Reference Pond 2.

		Fishes		Habitat	
Pond	**Year created**	**Species at risk**	**Fish assemblage**	**Aquatic macrophytes**	**Water chemistry**
Reference Pond 1	-	Contained all four species at risk, 69.9% of Pugnose Shiner were found in this pond.	Fish assemblage contained up to five predatory species in a given sampling event. The fish assemblage was stable over time.	Submerged vegetation was the dominant macrophyte. Consisted of <2% open water. Little change in vegetation 2012–2014.	Lower conductivity and less turbidity compared to created ponds.
Reference Pond 2	-	Contained all four species at risk.	Fish assemblage contained up to five predatory species in a given sampling event. The fish assemblage was stable over time.	Submerged vegetation was the dominant macrophyte. Contained the most open water out of the reference ponds. Little change in vegetation 2012–2014.	Higher conductivity and less turbidity compared to created ponds.